

Absolute Abundance and Survival of Juvenile Gags in Sea Grass Beds of the Northeastern Gulf of Mexico

CHRISTOPHER C. KOENIG AND FELICIA C. COLEMAN¹

*Institute for Fishery Resource Ecology, Department of Biological Science
Florida State University, Tallahassee, Florida 32306-1100, USA*

Abstract.—The absolute number of individuals and survival of juvenile gags *Mycteroperca microlepis* in a 15.4-km² shallow sea grass meadow in St. George Sound, Florida, were estimated by the Jolly–Seber mark–recapture method. Abundance was estimated within three sampling stations (150 m × 150 m) by means of standard (150 m, 1.8 km/h) tows with a 5-m otter trawl. The average densities (95% confidence limits), based on three stations sampled every 1–2 weeks from June to mid-September 1991, were 496 (251–744), 424 (210–670), and 549 (165–1,773) juveniles/ha. Trawl capture efficiencies and the effects of sea grass habitat conditions and size of juvenile gags were estimated so that absolute numbers could be determined outside the sampling stations. We estimated absolute abundance outside the sampling stations by trawling and dividing gag captures per standard tow by trawl capture efficiency estimates. The estimated absolute abundance of juvenile gags for the entire 15.4-km² area was 943,615. Survival of juvenile gags in sea grass was near 100%, as estimated from trawl capture rates over the sampling period. Survival estimates were generally variable but were confounded by emigration from the sampling areas. The small-scale spatial pattern of juvenile gags was random. The results of this work provide the basis for establishing a juvenile recruitment index by providing quantitative estimates of juvenile abundance.

Fisheries managers have recently turned their attention to habitat conservation because of the strong correlation between habitat degradation and fishery declines (Dayton et al. 1995; Arthur et al. 1996; Langton et al. 1996). Habitats in estuarine environments are of particular interest because of their proximity to human activity and their clear importance as nursery grounds for a number of economically important species (Butler et al. 1995).

Gag *Mycteroperca microlepis* is one of several warm-temperate reef species (including gray snapper *Lutjanus griseus*, lane snapper *Lutjanus synagris*, hogfish *Lachnolaimus maximus*, and black sea bass *Centropristis striata*) for which the estuarine environment plays an integral part in the early life history. A major portion of the Gulf of Mexico population of gag spawns on deepwater reefs of the West Florida Shelf (WFS) in winter (Coleman et al. 1996). Their pelagic larvae are transported to coastal sea grass beds (McErlean 1963; Gilmore 1977; Mullaney and Gale 1996), where they settle as juveniles and remain until autumn, when they move to nearshore reefs, a migration referred to as egress (Keener et al. 1988; Ross and Moser 1995; this study).

The objective of this study was to quantify total recruitment by estimating the absolute abundance (number of individuals), survival, spatial pattern,

and temporal patterns of settlement and egress of juvenile gags in sea grass beds of northwest Florida. Our results have important implications for developing alternative methods of stock assessment that incorporate fishery-independent (forecasting) methodologies rather than traditional fishery-dependent (hindcasting) methods.

Study Site

The sea grass beds of the northwest Florida coast form the only structurally complex habitat in the area. They are surrounded primarily by mud and sand, and there are no natural inshore reefs. Three sampling sites were set up within two adjacent sea grass beds located just off the Florida State University Marine Laboratory (FSUML) in St. George Sound in the northeastern Gulf of Mexico (Figure 1): stations 1 and 2 in the eastern sea grass bed and station 3 in the western sea grass bed. The criteria for selecting the sampling sites were (1) that they were located in shallow (1–2-m), uniform (not patchy) sea grass beds; (2) that they had different sea grass compositions and characteristics; and (3) that juvenile gags were present. Each of the three sampling sites was marked by buoys anchored at the corners of a square area (150 m on a side) and subdivided into six lanes (each 25 m × 150 m; Figure 1). The middle two lanes (lanes 3 and 4) were designated the mark–recapture (M–R) lanes, and the outer lanes (lanes 1, 2, 5, and 6) were designated reference (RF) lanes.

¹ Corresponding author: coleman@bio.fsu.edu

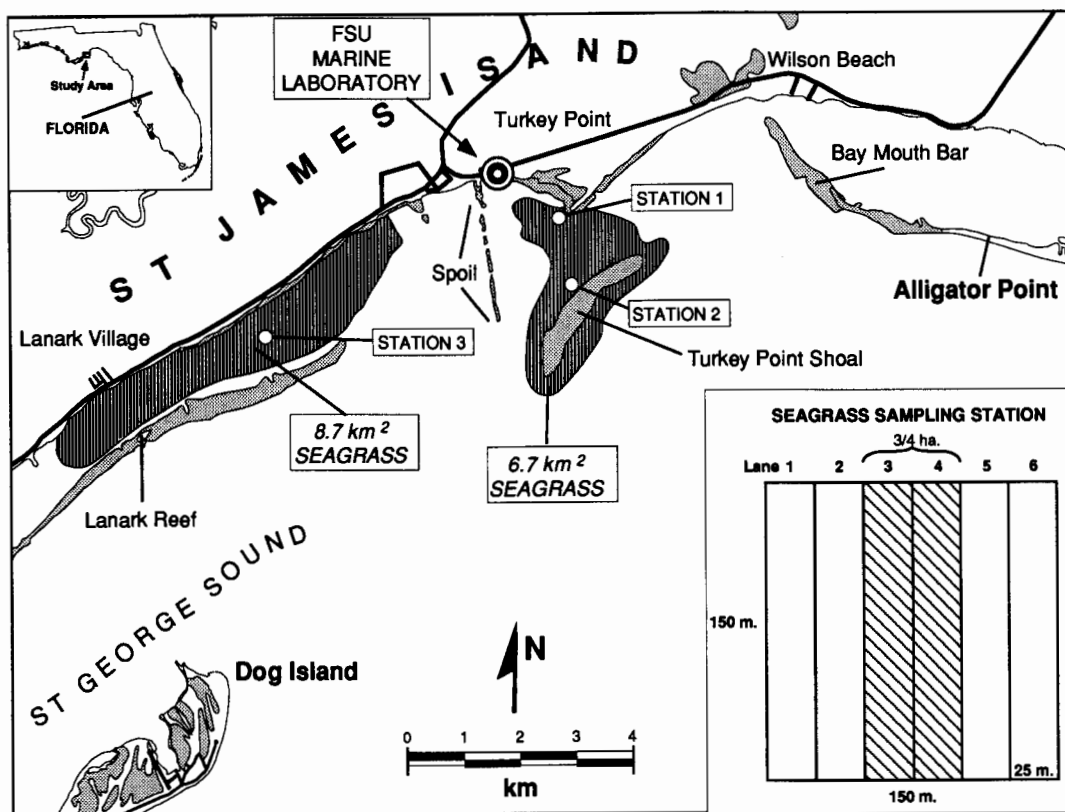


FIGURE 1.—Sea grass sampling areas (hatched area) and experimental design. Station locations are located off the Florida State University (FSU) Marine Laboratory in St. George Sound, on the northwest coast of Florida. The eastern sea grass bed was 6.7 km²; the western sea grass bed was 8.7 km²; lightly shaded areas are sand bars.

Methods

Absolute Abundance Determination

We used the Jolly–Seber mark–recapture method (Krebs 1989) to determine the densities of juvenile gags within the sampling sites. This method deals specifically with open populations, provides information on survival rates, and provides the opportunity to examine growth rates, movement patterns, and small-scale spatial patterns of individuals. We then used site abundance estimates to calculate capture efficiencies, which were then applied to the total sea grass area to develop abundance estimates of juvenile gags in two sea grass beds in St. George Sound.

Sampling protocol.—Juveniles were collected by standardized tow (1.8 km/h for 150 m) completed in 5 min with a 5-m otter trawl outfitted with a 3-mm-mesh liner in the bag end. The most efficient tow speed was determined by direct underwater observation; faster tows caused the net to ride off the bottom, and slower tows allowed

fish to escape. We determined the length of tow by balancing the collection of a sufficient number of gags for the mark–recapture study with sample size; very large sample sizes affect the functions of the trawl. Tows within lanes were randomized by the designation of 10 2.5-m-wide tracks (unmarked) within each 25-m-wide lane and the use of a random numbers table to select tracks. It was nearly impossible to tow precisely within tracks, but this procedure minimized unconscious sampling bias.

During each sampling event, trawls were deployed 16 times in the M–R lanes (eight tows per lane) and a single time in each of the four RF lanes. The RF lanes served as controls for the effects of trawling on the abundance estimates; trawling in those lanes was kept to a minimum. At each sampling time, water temperature and salinity were measured. Dissolved oxygen was measured several times during the sampling period just above the sediment surface and just before dawn, the place

and time at which minimum dissolved oxygen concentrations would be expected. Sampling was not scheduled at extreme low tides (when sampling depth was <0.7 m), because the propeller wash from the sampling boat could potentially disrupt sea grass and benthic organisms and probably influence juvenile gag catch rates.

Juvenile gags captured from the M-R lanes were immediately placed in aerated coolers, transported to the FSUML, and transferred to labeled plastic mesh baskets immersed in a 5,000-L tank supplied with running seawater. All RF-lane captures were returned immediately to their respective lanes. All first-time-captured fish from each sampling time in the M-R lanes were measured for standard lengths (mm, SL) and marked on the left side with a three-digit number specific to the individual and the sampling time. Marks were made by freeze-branding with devices made of 8–10-gauge copper wire that were cooled by liquid nitrogen. We avoided freeze damage to muscle tissues by limiting branding time to 3 or 4 s. First-time captures were branded, and their brand numbers and standard lengths recorded. Brand numbers of previously branded fish were recorded. All juveniles captured in the M-R lanes were released within 24 h in the lanes from which they were captured. The release procedure involved driving the boat in a zigzag fashion across the lanes and releasing fish haphazardly along the way. No fish died or were injured during any of these procedures.

All associated sea grass fauna, primarily decapods and fishes, were returned to the sampling lane from which they were captured. Many of the smaller species (e.g., caridean shrimp) did not survive the capture and release process.

The Jolly-Seber method assumes that (1) every individual in the sampling area, whether marked or unmarked, has the same probability of being caught in every sample; (2) every marked individual has the same probability of surviving from one sampling time to the next; (3) marks are permanent and legible throughout the sampling period; and (4) sampling time is small relative to intervals between samples.

A drawback of this method is that assumptions 1, 2, and 3 cannot be tested until the study is completed. Using the Leslie, Chitty, and Chitty test (Krebs 1989), we were able to test and support the assumption of equal catchability (assumption 1) within the marked population of station 2. Within the marked population, this test compares the estimated number of fish joining the population with the known number joining. For station 2 the dif-

ference was only 2%, so we assumed equal catchability. We tested the assumption of equal survival (assumption 2) by holding 40 marked fish in a 2,000-L laboratory tank for over 6 months. None died, and neither laboratory-held fish nor field-recaptured fish showed any evidence of irritation or infection around the brand marks. Marks were typically legible throughout the sampling period of June to early October 1991 (assumption 3); recaptured fish with fading brands were remarked with the same number. The fourth assumption was easily met because sampling time in this study was 1–2 d, and the interval between samples was 1–2 weeks.

Capture efficiency.—We calculated trawl capture efficiencies (E) for each station by dividing the mean number of juveniles captured per standard tow by their density, as determined by the Jolly-Seber method. We then determined juvenile density in sea grass areas outside of the sampling stations from the following relationship: density = $(10,000/S) (C/E)$, where 10,000 = the conversion factor for meters to hectares, S = sample area (m^2) per standard tow, C = the mean number of juveniles captured per standard tow; and E = capture efficiency estimate.

Juvenile density was then multiplied by total sea grass area of interest (ha) to yield the absolute abundance or total number of juveniles in the area of interest (Figure 1).

To evaluate the effect of sea grass characteristics on capture efficiency, we examined sea grass species composition, density (number of blades per unit area), and blade length (mm) at the three sampling sites in August when sea grass productivity was at a maximum. We chose 18 625- cm^2 quadrats from each site by picking three random coordinate sets within each lane to maximize dispersion and still retain randomness. Square quadrat frames were placed against the sediment, and all grass within the quadrat area was cut off at sediment level. The effect of sea grass density on capture efficiency was determined by examination of the area sampled during a standard tow.

The influence of juvenile gag size on capture efficiency over the size range used in this study (approximately 50–200 mm SL) was determined by comparison of the density estimates in the M-R lanes with those in the RF lanes over the sampling period. If both remained relatively constant over the sampling period, the influence of size on capture efficiency was considered negligible.

Spatial Patterns

We evaluated the spatial patterns (i.e., random, clumped, or regular) of juvenile gags in the sea grass beds by means of the variance-to-mean ratio of captures per standard tow and comparison of the sampling distribution with the Poisson distribution (Krebs 1989).

Survival.—Probability of survival from sample time t to $t + 1$ was equal to the size of the marked population at the beginning of sample $t + 1$ divided by the size of the marked population at the end of sample t (Krebs 1989). Survival as used here entails both remaining alive and remaining in the study area. That is, marked fish that leave the study area are counted as deaths. Thus, high survival estimates indicated both low mortality and low emigration.

Survival was also determined by regression of \log_e -transformed data for catch per unit effort (CPUE) on time (e.g., see Iles and Beverton 1991), the slope of which estimates mortality (Z); the power (β) of this analysis was estimated (Peterman 1990).

Times of Settlement and Egress

We determined settlement times for juvenile gags by counting presumed daily growth rings of the lapillus otolith following procedures in Brothers and McFarland (1981) and Keener et al. (1988). We did not directly validate daily incremental growth or settlement marks but instead relied upon the rationale of Keener et al. (1988) and upon the distribution of sizes over time, which indicated a single discrete cohort. There were three independent readers on all otoliths, and E. Brothers (EFS Consultants, personal communication) confirmed our counts on a sample of 20 otoliths. We determined egress times by tracking changes in density of juveniles over the estuary-dependent phase.

Results

Environmental conditions in the sea grass beds during this study remained relatively constant. Dissolved oxygen concentrations never fell below 5.0 mg/L during the sampling period. At all stations, salinity ranged from 26 to 32‰, and water temperature ranged from 28 to 31.5°C before early October. The first major cold front of the season, which occurred 4–6 October 1991, decreased water temperatures from 29 to 19–20°C at all stations.

Absolute Abundance

Repeated tows within a sampling time caused diminished catch per tow in the M–R lanes (Figure

2). Because of this decline, only the first three tows in each M–R lane were used to estimate relative abundance (captures per tow) in those lanes.

Mean capture of juvenile gags per standard tow in the M–R lanes was uniform early in the sampling period but declined during later sampling events at all three stations (Figure 3). Mean captures per tow in the RF lanes showed no such trend ($\alpha = 0.05$; Table 1). The significant declines in the M–R lanes apparently resulted from the intensity of the sampling effort in those lanes, even though all captured gags were returned to capture lanes. Thus, estimates based on M–R lanes underestimate the gag density in the general area, increasingly so from about mid-July to the end of the sampling period.

Although the mechanism for the progressive decline in the M–R lanes is unknown, our concern was that the apparent decline may have been caused by a movement of gags out of the heavily trawled M–R lanes and into the lightly trawled RF lanes. This occurrence, however, would be reflected in the progressive increase in catch in the RF lanes adjacent to the M–R lanes (lanes 2 and 5) over that in the RF lanes far from the M–R lanes (lanes 1 and 6). Such an increase would be reflected in greater slopes of regressions of CPUEs over the sampling period for lanes 2 and 5 than for lanes 1 and 6. The slopes for adjacent and nonadjacent RF-lane regressions are as follows: station 1, -0.0218 and -0.0199 ; station 2, -0.094 and -0.0229 ; and station 3, 0.0061 and 0.0103 . The patterns of decline (at stations 1 and 2) and increase (at station 3) indicate no consistent increase in RF lanes adjacent to M–R lanes, so refugees from M–R lanes are unlikely to have inflated catches in RF lanes. Therefore, we corrected density estimates for July, August, and September by dividing the RF-lane mean captures per tow (averaged over the sampling period) by the M–R-lane mean captures per tow (estimated from M–R-lane regression equations at the specific sampling time). The resulting factor was then multiplied by the density estimate of the same sampling time to yield a corrected density estimate (Table 2).

There were no significant differences in the relative abundances of gags among lanes at any station sampled ($\alpha = 0.05$). Homogeneity of juvenile distribution within sampling sites was determined a posteriori. Interlane differences for each station were compared for the first part of the sampling period only (i.e., before the divergence occurred).

Because captures per standard tow were constant in the RF lanes over the sampling period, we

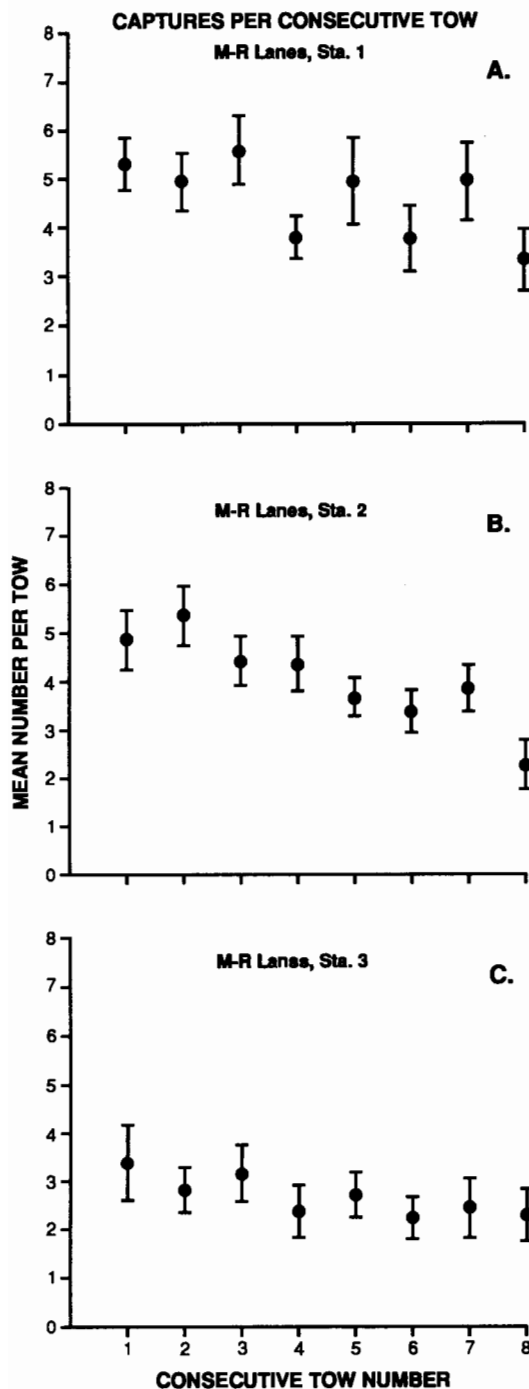


FIGURE 2.—Number of juvenile gags captured in mark-recapture (M-R) lanes in consecutive tows by station (Sta.), averaged over the sampling period. Vertical lines represent \pm SE.

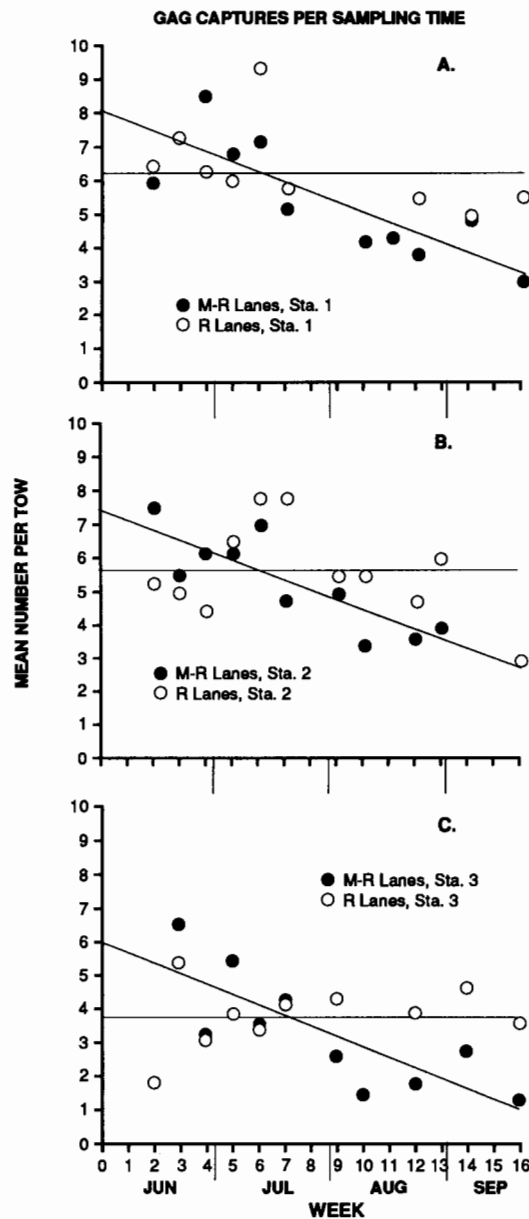


FIGURE 3.—Mean number of gags captured per standard tow in mark-recapture (M-R) lanes (filled circles) and reference lanes (R, open circles) by station (sta.), over the sampling period. Regression equations and significance levels are given in Table 1.

assumed low natural mortality and constant density in the general area. Therefore, we averaged the most precise estimates of density (i.e., those with the smallest confidence intervals) to estimate the overall density at each station (5, 9, and 20 August for station 1; 15 July and 1 August for

TABLE 1.—Linear regressions of juvenile gag captures per standard tow in St. George Sound, Florida, over the sampling period June–September 1991. Each of three sampling stations contained mark–recapture (M–R) and reference (RF) lanes; b = slope, a = intercept.

Station	Lane	b	a	r	df	F	P	Mean captures/tow ^a				
								Total	Jun	Jul	Aug	Sep
1	M–R	–0.286	7.811	0.51	56	19.7	<0.001	5.28	6.34	5.95	4.69	3.45
	RF	–0.142	7.451	0.25	33	2.14	0.153	6.34	6.34	6.34	6.34	6.34
2	M–R	–0.299	7.521	0.52	56	20.6	<0.001	4.93	5.59	5.58	4.26	2.96
	RF	–0.110	6.462	0.19	40	1.50	0.228	5.59	5.59	5.59	5.59	5.59
3	M–R	–0.240	5.079	0.45	55	14.0	<0.001	2.98	3.69	3.52	2.46	1.42
	RF	–0.049	3.297	0.09	43	0.37	0.547	3.69	3.69	3.69	3.69	3.69

^a The M–R values for July, August, and September were calculated from regression equations as midpoints of months. June M–R values were made equivalent to those of reference lanes.

station 2; and 31 July and 2 August for station 3). On the basis of these selections, the average density estimates for stations 1, 2, and 3 were very similar: 496, 424, and 549 fish/ha, respectively (Table 3).

We then determined absolute abundance in the

sea grass beds surrounding the sampling sites—the eastern bed, containing stations 1 and 2, and the western bed, containing station 3. The total number of juvenile gags in the eastern sea grass bed was 335,485 (95% confidence limits = 156,780 and 478,380) (Table 4). The absolute

TABLE 2.—Mark–recapture estimates of density and survival for juvenile gags from stations 1–3, St. George Sound, Florida, in 1991, according to the Jolly–Seber method. Estimates of the number of gags/ha and 95% confidence limits are adjusted to compensate for the trawling effect on the mark–recapture lanes.

Sample date	Proportion of population marked	Number of gags/ha	Probability of survival	95% confidence limits ^a for:			
				Gags/ha		Survival	
				Lower	Upper	Lower	Upper
Station 1							
26 Jun			1.000			0.545	1.000
1 Jul	0.075	1,132	0.338	398	2,814	0.154	0.794
8 Jul	0.153	497	0.466	218	1,081	0.226	1.000
20 Jul	0.086	1,146	0.309	393	2,817	0.180	0.553
5 Aug	0.169	378 ^b	1.000	186	613	0.660	1.000
9 Aug	0.258	587 ^b	0.818	292	860	0.490	1.000
20 Aug	0.406	524 ^b	1.000	274	758	0.506	1.000
4 Sep	0.458	1,109		340	3,324		
16 Sep	0.533						
Station 2							
25 Jun			0.587			0.275	1.000
1 Jul	0.065	449	0.767	184	1,166	0.437	1.000
9 Jul	0.138	799	0.409	341	1,458	0.240	0.727
15 Jul	0.242	364 ^b	0.598	186	561	0.376	0.979
1 Aug	0.218	484 ^b	1.000	233	780	0.838	1.000
5 Aug	0.256	1,052	0.578	483	1,675	0.294	1.000
19 Aug	0.216	1,168	0.871	515	2,004	0.317	1.000
27 Aug	0.348	1,038		340	2,730		
16 Sep	0.346						
Station 3							
24 Jun			0.421			0.141	1.000
2 Jul	0.062	593	0.702	164	2,506	0.251	1.000
10 Jul	0.086	959	0.617	262	3,374	0.210	1.000
18 Jul	0.078	1,319	0.361	381	4,266	0.127	1.000
31 Jul	0.182	475 ^b	0.693	147	1,474	0.219	1.000
2 Aug	0.146	623 ^b	0.841	183	2,073	0.180	1.000
22 Aug	0.214	783		169	4,205		
4 Sep	0.269						

^a Determined by the method of Manly (1984).

^b Best estimates averaged for overall density estimates.

TABLE 3.—Summary of abundance and capture efficiency estimates for juvenile gags captured from June to mid-September 1991 in sea grass beds in St. George Sound, Florida, corrected as necessary.

Location	Area sampled per tow (m ²)	Mean number of gags			Capture efficiency (%)
		Per hectare ^a	Area sampled/tow	Capture/tow ^b	
Station 1	300	496	14.9	6.3	42.6
Station 2	300	424	12.7	5.6	43.9
Station 3	225	549	12.4	3.7	29.9

^a Average of selected estimates from mark-recapture lanes.

^b Determined from reference lanes only.

abundance of juvenile gags in the western sea grass bed was 608,130 (95% confidence limits = 143,550 and 1,542,510). The combined total was therefore 943,615 (95% confidence limits = 150,565 and 1,010,445). In general, juvenile gag densities in the shallow sea grass beds in St. George Sound in 1991 were about 500 fish/ha or about 50,000 fish/km². The high variability in abundances in the western sea grass bed was attributed to sea grass characteristics; longer sea grass blades at that site caused lower trawl sample size and lower capture efficiencies.

Movement and Survival Patterns

The mobility of juvenile gags in the grass beds during the sampling period was low. Marked juveniles were caught repeatedly over the sampling period in the same relatively small M-R sampling area (0.75 ha) even though sampling intervals were from 1 to 2 weeks. Low mobility is also evident from high survival estimates, which specifically indicate low rates of emigration of marked fish.

Survival of juvenile gags was assumed to be high because of their highly cryptic behavior and coloration. The assumption of high survival was supported statistically and by the fact that very few (0.1%; 2 of 1,500 juveniles) were found in

poor or injured condition during the sampling period. Even though survival was typically variable among sampling times in M-R lanes (Table 2), a high probability of survival, because it was confounded with emigration, indicated low mortality and low emigration rates. Regression analyses of CPUE over the sampling period suggest low mortality in RF lanes. The daily Zs (including emigration) for stations 1, 2, and 3 were -0.00324, -0.00321, and 0.00272, respectively, but to define the limits of the mortality, we performed a power test on the regression of log_e CPUE on date of capture (≈age of cohort). With a power of 95%, mortality was less than 1%/d at all stations.

Spatial Distribution

The spatial pattern of juvenile gags was not significantly different from random within any sea grass locality sampled. The index of dispersion (I = variance/mean; Krebs 1989) for RF-lane captures per tow over the sampling period indicated no significant departure from the assumption of randomness (α = 0.05). The indices of dispersion at stations 1, 2, and 3 were 1.20, 1.18, and 1.48, respectively. Sample frequency distributions of reference lanes were also compared with theoretical Poisson distributions by means of the χ^2 test statistic and found not to differ significantly (station 1, χ^2 = 15.1, df = 14; station 2, χ^2 = 12.2, df = 11; station 3, χ^2 = 13.4, df = 8). Juvenile gags also showed random spatial patterns (α = 0.05) in other sea grass areas, such as along the northwestern end of Turkey Point Shoal (I = 1.13), just north of station 2 (I = 1.64), and just south of station 1 (I = 1.31). Significant departure from randomness was not observed at any sampling locality.

Capture Efficiencies

Grass beds contained three species of sea grass—shoalgrass *Halodule wrightii*, manatee

TABLE 4.—Estimates of abundance of juvenile gags in selected sea grass beds in St. George Sound, Florida, based on random sample tows taken outside designated sampling sites.

Sea grass location	Number of tows	Area sampled per tow (m ²)	Capture efficiency (%)	Gags captured/tow	Gags/ha	Sea grass area (ha)	Gags in sea grass area
Eastern beds							
Station 1: SE, SW	30	300	42.6	3.7	290	286	82,940
Station 2: SW	25	225	29.9	8.0	1,185	50	59,250
Station 3: NE	21	300	43.9	7.6	577	335	193,295
Total							335,485
Western beds							
Station 3: N, E, S, W	7	225	29.9	4.7	699	870	608,130

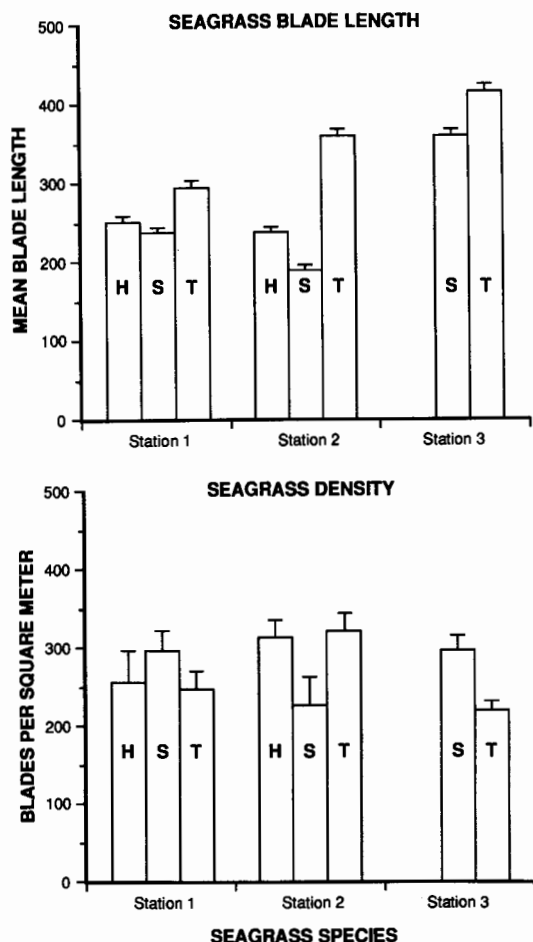


FIGURE 4.—Mean (\pm SE) sea grass blade length (mm) and density (blades/m²) for three species of sea grass at three stations in St. George Sound, Florida. Sea grass species are shoalgrass *Halodule wrightii* (H), manatee grass *Syringodium filiforme* (S), and turtle grass *Thalassia testudinum* (T).

grass *Syringodium filiforme*, and turtle grass *Thalassia testudinum*. The area of the sea grass bed sampled, as determined by trawl width, was influenced by biomass captured and grass density. For example, the opening of the trawl was wide at the beginning of a tow but narrowed as the tow progressed and the tail bag filled. The trawl mouth also narrowed and the trawl rode higher off the bottom in grass beds with longer grass blades because the blades produced a greater drag on the lead line of the towed net. The average trawl mouth width at stations 1 and 2 was 2 m and at station 3, 1.5 m. Thus, a smaller area was sampled per standard tow at station 3 because of the significantly longer sea grass blades (Figure 4). The ef-

fect of sea grass density on sample size and net efficiency could not be determined because densities were similar at all three stations (Figure 4). The areas sampled at stations 1 and 2 were 300 m² (2-m mean trawl mouth width \times 150-m tow length); the area sampled at station 3 was 225 m² (1.5 m \times 150 m).

Timing of Settlement and Egress

Pelagic juvenile gags recruited to the sea grass habitat as a cohort in April and May after a 40–43 d planktonic stage (Figure 5). A major egress of juvenile gags to offshore reefs took place concurrent with the October cold front (Figure 6). This conclusion is supported by the appearance of first-year juveniles on offshore reefs and in offshore crab traps within several weeks after this event (our own personal observation).

Discussion

Attempts to predict stock size and recruitment variability form the core of fisheries research (Hilborn and Walters 1992). The vast majority of these attempts rely on hindcasting models based primarily on historical catch records, but the unpredictable nature of recruitment makes historical records largely unreliable for predicting future fishery abundances. Because year-class strength is probably established in juvenile stages for many species (Sissenwine 1984), quantitative juvenile abundance estimates provide promising alternatives to traditional management models that could vastly improve our current ability to assess stocks. De Lafontaine et al. (1992) provide examples and a rationale for the use of juvenile forecasting models.

Three general areas must be considered in the development of a juvenile-based forecasting model for fishery recruitment: (1) juvenile habitat, (2) juvenile sampling, and (3) offshore movement and survival. Juvenile habitat includes aspects of habitat preference and relationship (physical, chemical, and biological), seasonal habitat distribution and areal coverage, and habitat quality effects on juvenile growth and survival. Sampling considerations are directly related to habitat characteristics that can affect sampling design and capture efficiency. Offshore movement and survival patterns can directly influence the accuracy of the forecasting model by affecting the regional connection between abundances of gags in sea grass and subsequent abundances in the offshore fishery. In the following discussions, each of these three components is addressed relative to juvenile gags.

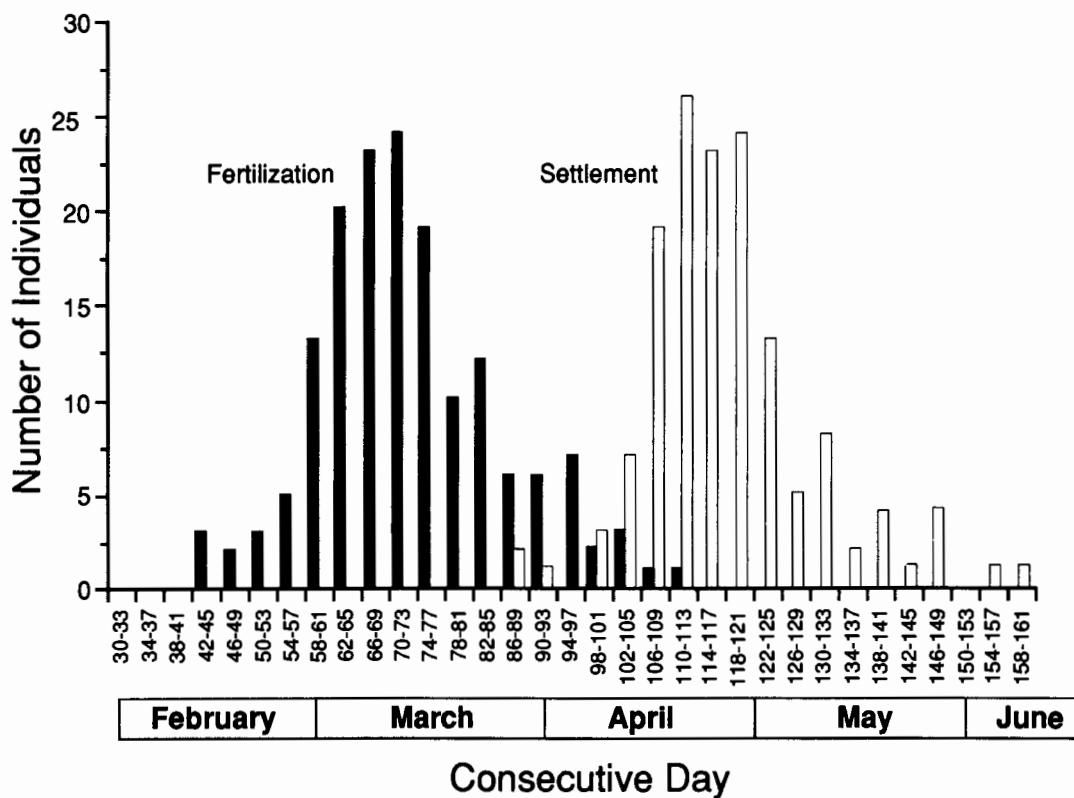


FIGURE 5.—Juvenile gags fertilization and settlement times in 1991, back-calculated from juvenile otolith incremental analysis. Numbers are day of the year (e.g., 1 = 1 January).

Juvenile Habitat

Many authors (McErlean 1963; Gilmore 1977; Heck and Thoman 1984; Mullaney and Gale 1996) have noted the presence of juvenile gags in estuaries during summer. Keener et al. (1988) and Ross and Moser (1995) considered the estuarine environment to be a consistent and integral requirement of early juvenile stages, primarily on the basis of their observation that such juveniles were abundant in high-salinity estuaries and virtually absent offshore. Numerous reef surveys in the north Florida area confirm that early juveniles do not recruit to shallow reefs (W. Lindberg, University of Florida, personal communication), with a few exceptions that occurred under unusual conditions (L. Kellogg, University of Florida, personal communication). Within estuaries, sea grass appears to be the preferred nursery habitat for this species, although the relative suitability of other estuarine habitats is unknown. In South Carolina, for example—where sea grass is absent—oyster reef is the dominant habitat for juvenile gags (Mullaney and Gale 1996). This study is the first to

document the high absolute abundances of juvenile gags in the sea grass habitat, which suggests that sea grass is a preferred habitat and supports the contention that estuaries are integral to the life cycle of gags.

The sea grass habitat of the northwest coast of Florida persists from mid-spring through early autumn (Zieman and Zieman 1989; Koenig, personal observation) and dies back over the fall and winter. Adult gags spawn primarily in February and March (Coleman et al. 1996), and juveniles recruit to sea grass beds in April and May (this study), when the sea grass habitat has recovered sufficiently from winter dieback to provide adequate protection for newly settled fish. Juvenile gags become susceptible to trawling in mid to late June, so abundance can be estimated from that time through early October.

In the present study, we found juvenile gag densities of about 50,000 fish/km² in two shallow sea grass beds in St. George Sound. Although all sea grass habitat is not equally suitable throughout its range, extensive juvenile habitat is available else-

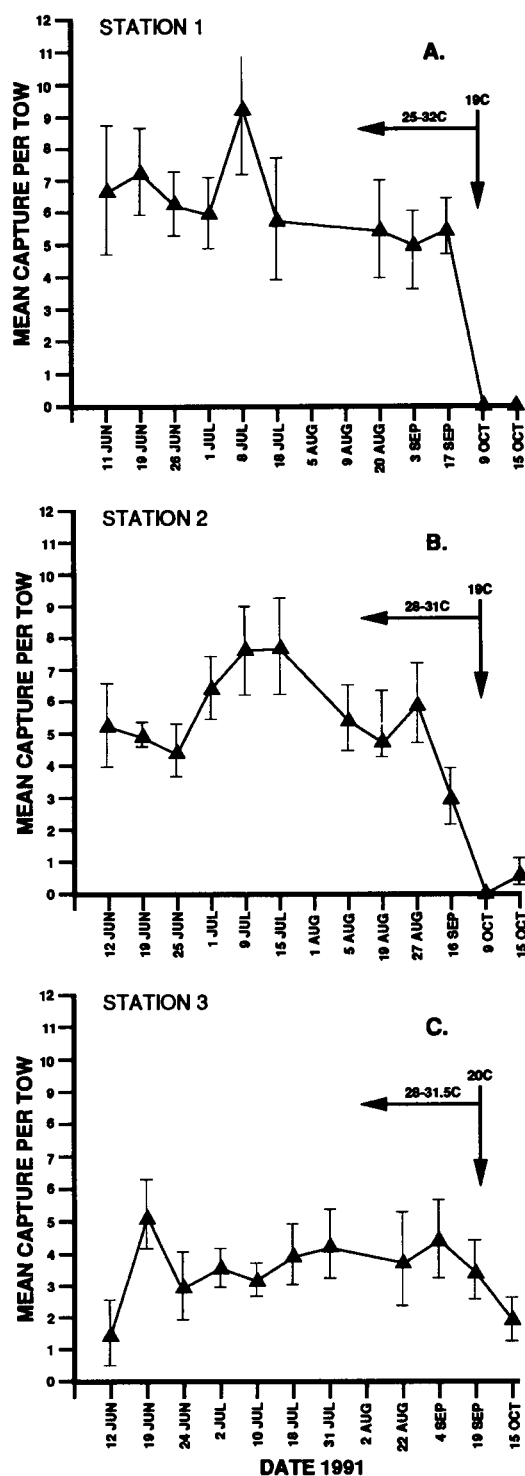


FIGURE 6.—Variation in average captures of juvenile gags per tow for three stations in sea grass beds of St. George Sound, Florida, from early June through Octo-

where along the west coast of Florida. In the Big Bend alone (from St. Marks south to Tarpon Springs, Florida), a 3,000-km² seagrass meadow occurs as a coastal band 11 to 35 km wide (Iverson and Bittaker 1986). Such an area has the potential to support 150 million juvenile gags. Other extensive, relatively pristine sea grass habitats occur along the west Florida coast in St. Andrews Bay, St. Joseph Bay, and Pine Island Sound.

Because critical sea grass habitats are generally close to shore, they are susceptible to anthropogenic disturbance, including storm water runoff (and its wide variety of dissolved contaminants), siltation through shoreline erosion, damage by recreational boats, additions of wastewater from pulp mills, and oil spills (Livingston 1987; Zieman and Zieman 1989). For example, the once extensive sea grass beds of Tampa Bay have declined by 81% as a result of anthropogenic impacts (Zieman and Zieman 1989), and extensive sea grass meadows south of Cape Sable in Florida Bay have undergone losses sufficiently radical to call into question their value as nursery habitat (Butler et al. 1995). Associated economic losses through the loss of fishery production have not yet been estimated accurately, but quantitative estimates of potential production of economically important species such as gag support adoption of measures to protect these habitats.

Juvenile Sampling

Many characteristics exhibited by juvenile gags in the sea grass habitat simplify the estimation of year-class strength. Because juveniles recruit as a single cohort over a short period of time (approximately 6 weeks) in April and May, all recruits are within a narrow size range at any sampling time during the summer months (McErlean 1963; Keener et al. 1988; Hood and Schlieder 1992; Ross and Moser 1995). In addition, juvenile survival rates are high, relative movement rates are low, and small-scale spatial patterns are random. Because the sampling efficiency of an otter trawl is similar over the summer months, juveniles can be sampled by otter trawl across localities, and the resulting estimates of abundance can be combined without

ber. Left-pointing arrows indicate water temperature ranges of 25–32°C (station 1), 28–31°C (station 2), 28–31.5°C (station 3); down-pointing arrow indicates a drop in water temperature to 19°C (stations 1 and 2) or 20°C (station 3).

introducing errors related to survival or size-related avoidance of the trawl.

Juvenile gags in north Florida sea grass beds represent an open population; that is, immigration and emigration of individuals occur continuously. However, given that juveniles exhibit very low rates of movement and tend to maintain uniform densities over the spatial scales represented by our study area, we can treat them like a closed population and apply more cost-effective methods to determine absolute abundance (e.g., catch-effort methods outlined in Ricker 1975; Krebs 1989). The small-scale random spatial patterns exhibited by juvenile gags also simplify sample-size determination and sampling-site selection.

Offshore Movement and Survival

Several studies suggest that the mass emigration of juvenile gags from estuaries is coordinated with weather patterns or rapid declines in water temperature (Keener et al. 1988; Ross and Moser 1995; Mullaney and Gale 1996). Our observations strongly support this contention, but other factors may be involved; some juveniles move out of the grass beds before the mass emigration that coincides with declining water temperatures (Hastings 1979; Ross and Moser 1995; our personal observations), and some juveniles remain to overwinter in the estuary (our personal observations).

Accurate fishery recruitment forecasting requires the types of information on the estuary-dependent juvenile stage that we have presented here. In addition, it requires a knowledge of juvenile survival and movement after egress from the sea grass environment. Survival of late juveniles in the offshore reef environment is unknown, but we have good evidence that large juvenile year-classes from north Florida estuaries correspond to significant fishery production on a regional level (Johnson and Koenig, in press). The contribution of strong year-classes, however, may be dampened by density-dependent factors, including cannibalism of juveniles by adults on offshore reefs (W. Fable, National Marine Fisheries Service, personal communication) and forced movement of juveniles from shallow reefs to deep reefs (>50 m), which increases their susceptibility to fishing-induced mortality.

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